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ABSTRACT

The Alice/Collaborative Inquiry Testbed ("Alice Testbed") is one of four testbeds designed to demonstrate the educational potential of telecommunications. Their long term goal is to establish the effectiveness of Network Science and to develop key aspects of the technical, human, and conceptual infrastructure necessary to scale up Network Science in order to make this approach to science learning widely available to students from upper elementary through high school. This paper articulates two conjectures that form the basis of the Alice Testbed: (1) geographically-distributed groups of students who begin with a common problem, collect and share data, and discuss their findings; (2) development of the appropriate infrastructure of products and services to support widespread use of Network Science (scalability). Also included in the article is a summary of the innovation at the core of the project and the model developed for a testbed project as well as insight gained from the initial months of working on this project. (ZWH)

Demonstration

Contents:
Collaborative Inquiry in Networked Communities

Location:
Demonstration Room

Collaborative Inquiry in Networked Communities: Lessons From the Alice Testbed

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TERC

Abstract

This paper articulates the two conjectures that form the basis of the Alice Testbed: the effectiveness and viability of Network Science and the scalability of this model for learning. After summarizing the innovation at the core of the project and the model we have developed for a testbed project, we report on what we have learned from the initial months of work. Descriptions of the six testbed projects are included in the Appendix.

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Background

The Alice/Collaborative Inquiry Testbed ("Alice Testbed") builds on a decade of work at TERC devoted to developing curriculum and software to enable students to do collaborative inquiry using telecommunications. The model of science learning that we call Network Science has emerged from a series of TERC projects; at present these projects include NGS Kids Network/Middle Grades and Global Laboratory III. In this model of learning, students at a variety of sites work collaboratively to collect data; they then organize and analyze the data and share their findings with others. Topics for Network Science units are often environmental, and have included investigations about the quality of drinking water, the level of ozone, and the effects of ozone on animal and plant life.

The Alice Testbed is one of four NSF-funded testbeds designed to demonstrate the educational potential of telecommunications.

> The testbeds are not simply demonstrations or existence proofs. They are testing high-risk conjectures about new paradigms for learning and teaching, and they will not necessarily succeed in the manner originally envisioned. The testbeds are designed to advance our collective know-how and understanding in a way that builds upon the prior and current experience of other groups, and contributes systematic knowledge to the larger community. During this pilot phase, each testbed is developing a comprehensive research agenda. (B. Hunter, 1993, p. 1)

The long-term goal of the Alice Testbed is to establish the effectiveness of Network Science, and to develop key aspects of the technical, human, and conceptual infrastructure necessary to scale up Network Science, in order to make this approach to science learning widely available to students from upper elementary through high school. There are two conjectures–each in the form of a model–which form the basis of the Alice Testbed. The first model describes an approach to science learning, Network Science, that includes geographically-distributed groups of students who begin with a common problem, collect and share data, and discuss their findings. A second model describes the development of the appropriate infrastructure of products and services to support widespread use of Network Science (scalability). In taking the initial steps towards implementation of these models, the Alice Testbed is providing data about the effectiveness and viability of each model.

Network Science Model

The model of Network Science–shorthand for collaborative science inquiry in a networked environment–emerges from an understanding of learning as grounded in students' construction of meaning from their experiences, as well as an understanding that effective science education should incorporate activities that closely resemble those of real scientists.

Network Science has the following characteristics:

- *Investigation of real science problems.* Network Science uses the study of real-world problems or phenomena to motivate a deep understanding of science processes and concepts. Network Science units focus on topics such as water quality, flora and fauna of the wetlands, air quality and ozone levels, and the human body. For many science investigations, the geographic distribution of sites provides important variation in data, e.g., in the collection of data about acid rain.
- *Collaboration.* At the heart of Network Science is the collaboration of individuals and groups as they work on a common investigation, both within each classroom and among geographically remote classrooms. Collaboration has the power to motivate students by providing an authentic audience for their work. *Within each classroom* , as students start engaging in science processes, they discover the practical as well as the intellectual strength of working as collaborators, sharing responsibilities, and building on each others' ideas. *Among geographically-remote classrooms*, students discover a motivating context for sharing their data, their ways of looking at the data, and their findings. Network Science also fosters the collaboration of scientists, volunteers, facilitators, and experts with students and teachers.
- *Shared goals.* While collaborators may be geographically remote, they are tied together by a common problem or agenda. They may all be investigating the effects of ozone through a single approach (use of Global Lab's Total Column Ozonometer); or sites may be designing related experiments and requesting data from each other. The work of students in one classroom is fit into a larger effort of others, mirroring how scientists work.
- *Shared data.* Since data are shared among all sites, standards for reporting are necessary. These standards may be part of a pre-set curriculum, or developed by participants. Ideally the work of all collaborators is shared via one or more databases that include text, tables with numeric, categorical, or descriptive data, graphs, maps, drawings, or photographs. This model gives students an opportunity to generate and analyze real data: collecting, organizing,

graphing, mapping, observing patterns, interpreting, and questioning.

- *Shared knowledge-building.* The shared data forms the basis for analysis and interpretation among all collaborators. The resulting knowledge and reflections are distributed among all participants, generating discussion and further questions. The model of understanding is one of constructing knowledge through a process that begins with questions, involves students collecting and analyzing data, and results in discussion of findings among a larger group.

- *Technology-enhanced projects.* Other telecommunications projects typically limit their use of technology to the use of word-processors and telecommunications; in contrast, Network Science projects encourage the use of data tables, graphing, and display of data on maps–all now readily available as computer software. Some Network Science curricula are also characterized by the use of other technologies to enable students to measure their environment. For example, the Global Lab has invented a simple Ozonometer for measuring ground-level ozone, based on the rapid deterioration of a natural latex rubber thread caused by ozone.

While we refer to Network Science as a model of science learning, it is a model that allows for a range of implementations. Some of these projects are very prescribed in their activities (e.g., NGS Kids Network). Others begin with the development of skills and work toward student-initiated projects (e.g., Global Lab). It is helpful to differentiate between two groups of Network Science projects. The first is large projects that serve hundreds and possibly thousands of classrooms, on the model of National Geographic Kids Network. These projects typically charge fees for a package that includes curriculum materials, telecommunications, and specialized services such as Help Hotline assistance. In contrast to these well-know projects, there is a second level of projects evolving, which we call Groundswell projects. This second group consists of numerous projects each involving a small number of classrooms (or possibly just a handful of students) who are investigating a question proposed by one of the group. These projects, similar in structure to the projects that emerge from the "Calls for Collaboration" used by Global SchoolNet (FrEdMail) participants, are distinctive in their ability to exchange and analyze data in addition to exchanging messages, because of their use of the Alice Network Software.

It is instructive to locate this model on Riel and Harasim's typology of approaches to Network Learning (1994). This model incorporates elements of four categories. Network Science is clearly an example of Cross-Classroom Collaborations, characterized by "extensive and reciprocal interactions among a small group of classes" (p. 2). But it also envisions the participation of scientists and other experts, and encourages professional development of teachers through network communication ("TeleApprenticeships" and "Professional Development"). Most notably, in the focus on data sharing and data consolidation, the model might well be seen as an important extension of the category of "Information Network RetrievalDatabases and Archived Information." In Network Science, the databases are constructed by students as part of a project during a limited period of time, or incrementally over a period of successive years. In short, the model for Network Science described above can be usefully viewed as a combination and extension of several categories of Riel and Harasim's model of Network Learning.

Scalability

The Alice Testbed is also investigating scalability of Network Science. The model being developed is one of the evolution and growth of the educational market for telecommunications services; these services will form a robust infrastructure for widespread use of educational telecommunications.

> The dream is that by the year 2000 there would be dozens of educational service providers (ESPs) offering products and services based on Alice user and host software. Such a rich set of services would be available that schools and teachers at all levels would demand and obtain Alice and Internet connectivity through a variety of networks; perhaps 500,000 classrooms (20% of the U.S. market) would be connected. At the same time the large number of users continues to attract new offerings often generated from the educational community funded by grants of various types and then turned over to ESPs. There are several technical service providers who, under contract from some of the ESPs, perform the technical work associated with offering an educational service over the network: setting up accounts, creating templates for exchange of data, creating working groups, running the computers, keeping backups and archives, etc. National Geographic Society, as the first in the business, has a wide variety of outstanding curricula available, including almost two dozen Kids Network units and the Global Lab curricula. Numerous states have projects underway to provide pre- and in-service support for teachers. (from R. Tinker, 1992).

The Alice Testbed aims to define the steps necessary to achieve the level of services described. Our work includes partnerships with ESPs, including National Geographic Society and BBN, and with other projects at TERC. These partnerships are providing initial assessments of the what services will be needed and how to make the services self-supporting.

The Software Innovation

The fundamental innovation element that characterizes the projects in the Alice Testbed is the set of tools provided to students and teachers by the Alice Network Software. Understanding the design of the software is helpful to understanding Network Science.

> Different pedagogical goals will suggest different approaches to large-scale computer use and will require different kinds of technological and other support. A pedagogy emphasizing the acquisition of basic skills suggests the use of an integrated learning system in which skill practice is individualized and sequenced. ... In contrast, a pedagogy emphasizing apprenticeship as a means for attaining higher cognitive skills and understanding (Collins, Brown, & Newman, 1989; Resnick, 1987) suggests modeling school computer use on adult work activities. Each vision of education includes a unique image of how computers function in the classroom organization. (Newman, 1990, p. 10)

The Alice Network Software, often described as "tool-based software," is designed to give students tools for working with data analogous to the tools that scientists have.

The elements of this innovation are described below.

Common set of tools, available on both the Mac and PC platforms. The software has been created on both the Mac and PC/Windows platforms, enabling users to telecommunicate to other users on either platform. Each user has an identical set of tools to view others' data, graphs, maps, and written messages, without having to translate. This innovation makes the task of sharing messages (including simple formatting) and data tables among users much easier–an essential element in collaboration.

Data analysis tools. In order for students to interpret data, they need tools for data analysis. The software assists students in creating multiple ways to look at data. The software is built around a data table. Students can collect data using a data table, then analyze their data by sorting the data, looking at subsets, or by examining a variety of statistics (mean, mode, maximum, minimum, etc.). Students can look at their data one record at a time in the "forms view," which is often used for entering data. A variety of graphs can be automatically generated from the data. Once created, these graphs can be manipulated (e.g., changing the maximums and minimums on each axis) and saved. Data sets which includes longitude/latitude information give student another option, that of looking at a map showing the geographical distribution of a measurement (e.g., acidity level of rain). They can organize the display and save the representation. Data tables can be imported and exported; this allows students who wish to use more sophisticated tools to analyze their data, such as spreadsheets and geographic information systems.

Word processor and e-mail. The software incorporates a simple word processor that doubles as a mail reader/writer. Students can describe their experiment, detail the steps of their data analysis, and share their findings with others in their class (by printing) or at remote locations (via e-mail). The word processor/e-mail reader allows for simple formatting (bold and italics) which assist students in articulating and organizing their ideas.

Telecommunications. Telecommunications functions have been designed to make Internet email available to schools that only have modem-access to host servers through low-bandwidth phone line connections. (As wide bandwidth connections to schools expand, the Data-Analysis Tools will be adapted to use the increasingly-available IP mail protocols.) This design is typical of large educational networks, such as TENET in Texas and NEXUS in Australia. Any terminal-type user of TENET and NEXUS is now able to use the Alice Network Software on an existing account.

The Alice Network Software's telecommunications module was intended to replace standard modem-based telecommunications software, which is poorly designed for classroom use. In typical telecommunications packages, the interface is complex and users have to understand a complex sequence of actions, including choosing the protocols by which to make file transfers. In contrast, the Alice Network Software automates telecommunications through the use of "scripts." Users place multiple files to send in an OUTBOX, addressing each one individually. They can initiate telecommunications when convenient by pressing one button and filling in a password; and then check their INBOX for mail received. In addition to automating telecommunications, the design of the system allows for an easy method of distributing updated files. When the project coordinator (or any teacher) needs to send out new data templates or address books, these items are mailed to participating classrooms as "updates" and are automatically installed when the user moves them from the INBOX.

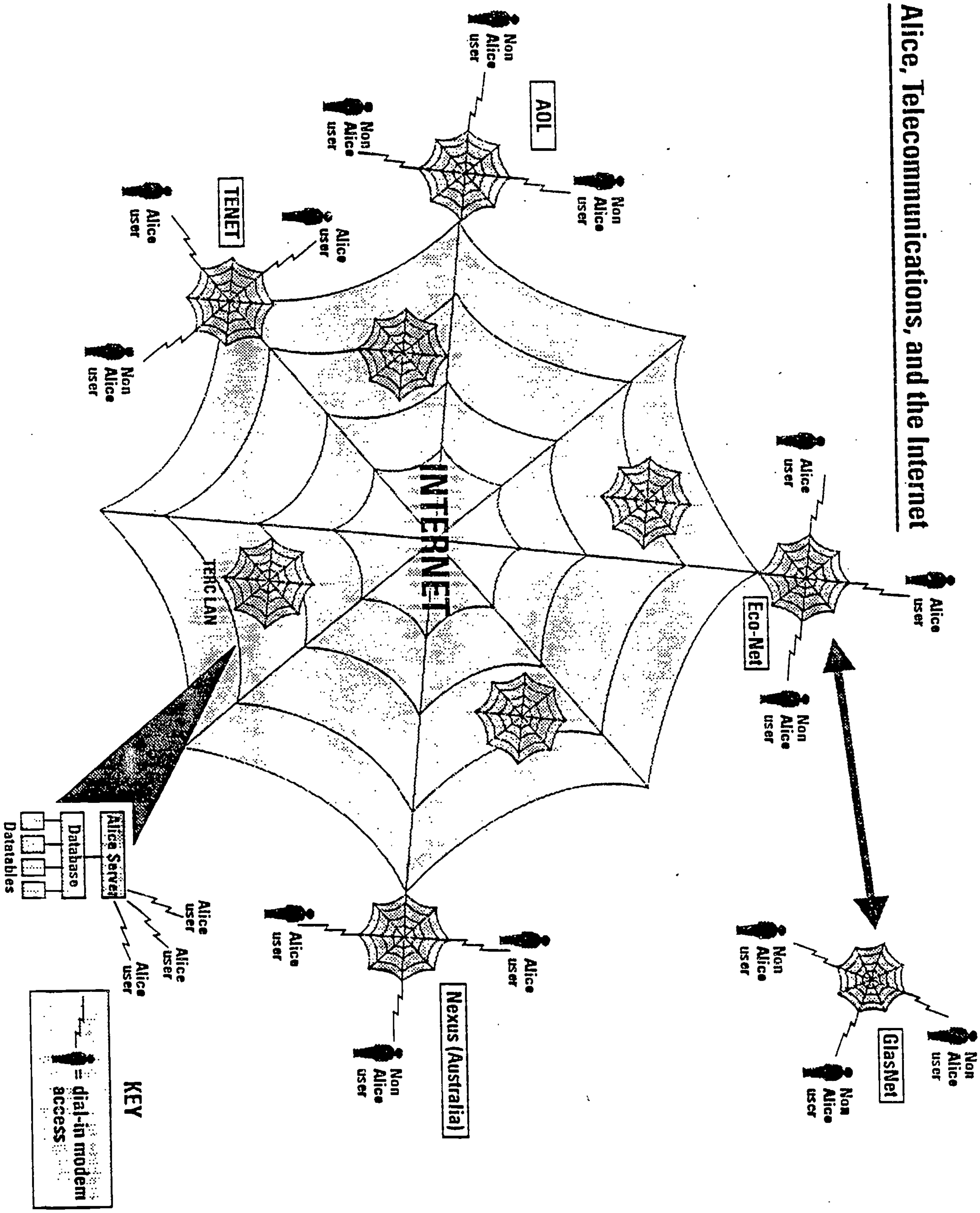
The Alice telecommunications module enables students to exchange their data tables, maps displaying data, and graphs (i.e., their representations of the data), and their writing (i.e., their interpretations of what they have learned). The ability to telecommunicate all this information together–far more than words–is an essential element of Network Science.

Data consolidation. Prior to the availability of the Alice Network Software, student collaborations were limited to sending individual e-mail messages among sites. If data were used, it was incorporated into these messages and each site would retype the data into whatever data tools there were using. The Global Lab project reported that few classes, under these circumstances, analyzed data from other sites. Using the Alice Network Software and an Alice server, data from a variety of sites can be submitted to a single database where it is combined into a single table. When students send a "retrieve" message, they receive the full set of data from all schools who have submitted. Students can retrieve information that has been collected from hundreds of sites, which enables students to have access to significant scientific data. Currently the testbed is making use of an early-version prototype for data consolidation.

Compatibility With Non-Alice Users. The software has been designed so that it can be mimicked by sites that are not using Alice Network Software, e.g., sites that do not have access to EcoNet or to an Alice-enabled Internet host, or sites which cannot run the Alice Network Software (pre-Windows PCs or Apple IIs). These sites, typically at the locations most remote from the United States such as eastern Europe and Africa, are able to participate fully with schools who have more modern computers. The Global Lab project includes sites which are not using the Alice Network Software, constituting an estimated 50% of their schools.

The interrelationships of the Internet, various hosts, Alice and non-Alice users, and the data consolidation server are shown in the diagram on the next page.

Alice, Telecommunications, and the Internet



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It is important to note that the Alice Network Software, in its current form, is designed to make use of technology that either is already available in many schools, or that schools are able to purchase. The key elements of this technology are a computer, modem, and telephone line. We view this strategy of terminal-host dial-up connectivity as a transitional one, emphasizing widespread availability over "cutting edge" technology. The rapid growth of standards and software on the Internet and the increasing number of schools with client-server connections to the Internet make it certain that, at some point in the future (one that is presently difficult to determine), Network Science will be best supported with data-analysis tools that are part of a communications tool designed around full Internet connectivity.

Testbed Projects: Developing a Model

Following several months of planning with collaborating projects, the pilot phase of the Alice Testbed got underway in September 1993 with the distribution of a functional prototype of the Alice Network Software. Global Lab distributed the software to its 120 participating schools (40 outside the United States) in September. Since then, five additional projects have joined the testbed; the most recent, in Quincy, Massachusetts, consists of 20 teachers from two schools, one elementary and one middle school. These two projects bracket our experience to date over six months: one large testbed project, initiated by TERC and funded by an NSF grant; one small testbed project, initiated by a group of teachers, and funded by a small state grant. Each of the six projects is helping us define the educational potential for Network Science and the issues of deployment.

Alice Testbed Projects (as of 3/15/94)

Name	Number of Sites	Dates
Global Lab Building Investigative Skills and Research Strands	120 schools, including 40 outside the U.S.	9/93 thru 6/94
EPA/Nebraska Wetlands	26 schools, distributed across U.S.	10/93 thru 11/93
TERC/Kids Network Field test of Human Body curriculum	31 schools, distributed across U.S.	2/94 thru 3/94
TERC/Kids Network Field test of Water Quality curriculum	52 schools, distributed across U.S.	4/94 thru 5/94
EPA/Nebraska Amphibians as Bio-Indicators	23 schools, distributed across U.S.	3/94 thru 5/94
Quincy Public Schools Black Creek Estuary Study	20 teachers in 2 schools, all in one city	3/94 thru 5/94

Both TERC/Kids Network and EPA/Nebraska have organized and run two projects. As the second of the pair is currently getting underway, we are in a good position to see if the lessons learned from the earlier project are being effectively used to inform the second project. Note also that these projects vary greatly in size and organization. The Quincy Public Schools project is a Groundswell Project, having been initiated by teachers.

We anticipate additional projects joining the Alice Testbed in the coming months, including AIRNET, an air-quality monitoring project that has grown out of the work of three high schools in New Hampshire. We are considering incorporating our model of Network Science into several teacher workshops this summer; from each of these workshops we expect that one or more projects may emerge.

The process of working with each group to define their participation in the testbed has led to clarification about the various components that make up an Alice Testbed project. We have distilled our understanding of these components, and use the model shown below with our potential project collaborators to define the characteristics of each project within the testbed.

Descriptive Model of Testbed Projects

Component	Comments
Organization	
goals and purposes	Is the group clear about what it wants to achieve? What is the group's understanding of Network Science?
selection of sites	Identify how project will be announced; how sites will be selected; what equipment and time are needed, grade range, expectations for participation.
coordination and scheduling	Create schedule that reflects schedules of school sites, e.g., vacations. Maximize flexibility for all participants.
funding	Identify costs, funding sources, responsibilities.
network support, software support	Identify individuals responsible for support functions among school staff, state department of education, publisher, Alice Testbed staff, other project staff.
general	Will the level of organization, amount of funding, and skill of participating teachers and students support the goals and purposes?
Model of learning	Are activities structured and uniform among classes? How much variation is allowed among classes? within a class? Are students encouraged to develop their own questions, and to explore these questions?
Participants	
sites	Number and distribution, languages spoken, school schedules.
teachers, students	Background with technology, science, other networked science projects; grade levels; subjects; goals and motivations for participating.
Teacher development	What are the goals of the teachers? How will this project help them reach them?
model of learning	Teachers need to understand the model of learning in the curriculum: process and content goals, learning strategies.
curriculum training	Teachers need familiarity with the curriculum, especially if collaborative inquiry is new.
software training	Teachers need familiarity with the software: another teacher? a student? videotape? tutorial? exploration?
on-going support	Identify who a teacher can go to with questions about the curriculum, or about the software.
	How will the project support the professional development of the teachers? Use electronic forums? face-to-face meetings of local teachers? mentors?

Component	Comments
Curriculum content pedagogy network strategy external review	Identify responsibility for curriculum, and whether outline, resource book, or detailed plan is being created. In addition to content and pedagogy, network curricula need a clear model for network use. Schedule time for review of curriculum materials.
Research student assessment project assessment	Teachers most often assess their students; can their assessment be shared? Identify any common instruments to be used. What approach, what questions, what data, who will collect, who will analyze. Key questions: what evidence do we have that students are learning? what are they learning? is the curriculum or approach ready for dissemination?
Network Resources data consolidation server on-line scientists	Identify resources. Who manages the server, setting up data tables in the database, fixing problems, and creating reports. Who selects, orients, maintains liaison.
Technologies for sites connectivity software others	Through which network(s) will the participants communicate; what are the costs and how are they covered. Alice Network Software, or other, or mixed; additional software for data analysis (spreadsheets, GIS). Examples: measuring instruments for ground level ozone, atmospheric ozone (TCO).
Partnerships	Organizations bringing resources: content knowledge, technology skills, network access, funding, experience in network science.
Dissemination editorial and quality review publishing marketing financial responsibility and benefit	For many projects, dissemination of their materials is an important goal. Identify responsibilities in these key areas.

What Have We Learned About Network Science?

Rather than starting with the *idealization* of an innovation and creating measures, we have focused at efforts in looking at the *realization* of the innovation in multiple contexts. The idealization is the model described earlier in this paper. Realizations are not only different from the idealization, but they are distinct from each other; they are the result of taking the model and bringing it into the extraordinarily complex world of the classroom–and in this case, the marketplace as well. (Bruce and Rubin, 1993, pp. 197-215)

In Bruce and Rubin's study of QUILL, a computer program designed to help upper elementary student to develop as writers, they reflect,

> It is no simple matter to look beyond preconceptions to see what happens when computers are used in education. ... The process of adopting a computer-based innovation is often a gradual one, so that characterizing the use of innovation requires long-term study. The relevant variables are often unknown at the beginning. And much of what students learn, especially with significant innovations, is not captured by standard assessment techniques, so that new methods of evaluation must be developed. (Bruce and Rubin, 1993, p. 216)

Newman (1990) makes a similar point.

> ... the unit of analysis is the classroom or school, hence it is necessary to experiment in real settings over a period of time sufficient for the environment to appropriate the technology

In short, innovation in general, and educational technology innovation in particular, is typically a gradual process, one that must be studied over time with great attention to the variety of contexts that shape the way that the innovation develops.

Needless to say, the initial months that the Alice Testbed has been operational have not given sufficient time to make general assessments of the viability and effectiveness of Network Science as a model of science learning. Rather, we are in a position to discuss issues and obstacles that have emerged across the initial testbed projects. Our ability to understanding and address these issues will significantly shape the testbed in the future.

Participation and completion rates. While participation rates are consistently high (90% of better) among teachers who have signed up for a project, we wondered about the few teachers who did not show up at all on-line. For example, in the EPA/Nebraska Wetlands project, 29 teachers signed up initially and 26 participated. This raised an important question about obstacles to participation. We attempted to surveyed those few who did not participate. Among the Wetlands teachers, one declined to participate because his class's schedule did not allow participation in the live video uplinks that this project was using, and he did not want to participate partially. Another was not able to participate because the phone line provided did not permit toll calls. Of the 26 Wetlands teachers who participated in any way, 21 submitted data to the database (81%). We have not yet examined completion rates for any of the projects.

How do these rates compare with similar projects for whom telecommunications is limited to messages? Riel (1994) reports that, in her "task phase analysis" of 110 classes participating in Learning Circles on AT&T's Learning Network, most responded to a "roll call" at the beginning of the session, 86% of the classes sent one or more messages during the initial two weeks, and 75% completed the project.

Scheduling. Anyone who has taught knows how difficult scheduling issues can be at any one school. Students leave early for athletic games, or are gone for an entire day for a field trip in another class. This winter, especially, classes were canceled for weather reasons–in some cases, up to a week at a time. When considering how complex the scheduling issues are for any *one* school, we were not surprised to observe the dissatisfaction expressed by teachers when faced with rigid schedules for the testbed projects. In addition to teacher dissatisfaction, failure of teachers to meet schedules appears as a common problem for projects that try to tie teachers to a very tight schedule.

Projects are beginning to experiment with less restrictive schedules. In the EPA/Nebraska Amphibians study, which began in March, a schedule has being developed that will allow classes to submit their data about amphibians populations over the course of a month. This schedule allows for the very different climate variations from north to south, which results in the emergence of the amphibians at different times.

Perhaps the most interesting example of a teacher unable to meet the schedule for an introductory message came from a Global Lab teacher in Moscow in September '93. This teacher wrote an apology to her teammates, explaining that her initial submission would be late because her school was near Russian White House, and because of the fighting, school would not be in session for a few more days.

The issue of scheduling of curriculum has another dimension as well. When the curriculum is very full, classes are kept busy with their activities and little time is available for classes to discuss their work with each other. This over-scheduling was reported by teachers in both the Wetlands and Global Lab projects. The Global Lab project has since been substantially pared down, with the goal of giving teachers and students more time to discuss ideas with other classes.

Curriculum. The writing of curriculum for Network Science has presented some difficulties in the initial projects. Some projects have asked people to write curricula who may be experienced curriculum writers, but who are not familiar with telecommunications nor with the specific software being used.

There is also need for experience in writing data templates that lend themselves to appropriate graph and map displays.

In response, the Alice project has begun to request review of each group's curriculum, with the goal of encouraging additional consideration about appropriate use of telecommunications. The project has also outlined, and is in the process of writing, a Handbook for Curriculum Writers and Administrators that documents strategies for telecommunications and reflects what has been learned in these initial field trials. Examples:

> The importance of classes having an introductory unit, which has the dual purpose of beginning to build a sense of community and also serves to introduce them to the technology.
>
> Clarify the different types of telecommunication activities: e-mail sent to one class, to a cluster, or to the entire set of participating classrooms; data tables sent to one class, to a cluster, or to the entire set of participating classrooms; submission of data to a server; and retrieval of data from the server.
>
> Avoid close dependency on schedule. A schedule must be flexible and allow for the unpredictable events that are certain to occur. Schedules may be helpful in encouraging participation, but classes must be able to submit late and still continue to participate.

Design for data submission. Our initial experience shows that the present design for submitting data is not sufficiently flexible. For many purposes, it is desirable to create a table with one row per site containing multiple fields. The user fills out one set of fields (i.e., part of one row), submits the data for the other classes to analyze, and then submits a second time when all the fields are completely filled. Under the present design, the network manager had to manually delete rows from the database to avoid duplicate information. We are considering giving each submission an identifier so that, when users make multiple submissions of this type, each submission will automatically update the previous entry.

Tools for project management. Network managers report that it is very difficult to know what is happening in multiple classrooms across the project. In response to their needs, we developed a database reporting system which sends a message each morning (or at any requested interval) about all submissions to a database during the previous 24 hours. With this information, we have been able to track participation more readily. We are currently working on understanding other tasks of the network manager, and adapting our database design to automate them when possible.

Multiple technologies. We are looking at the effect of using multiple technologies within a testbed project. One notable success has been the Total

Column Ozonometer, a simple tool designed and distributed by Global Lab. On the other hand, the EPA/Nebraska Wetlands project used live video uplinks twice a week with an audio bridge. Some of the teachers reported that this technology was very inflexible in its scheduling demands; some reported that they used videotapes of the broadcasts with their classes, and others did not make use of the broadcasts at all. The second project organized by EPA/Nebraska is not using live video links; they may distribute information by videotape. Further work in the testbed projects will continue to look at what additional technologies enhance Network Science.

Electronic Forums for Teachers. All of the testbed projects have set up "electronic forums" to encourage discussion among teachers. These typically consist of a "mailing group" or other straightforward means for teachers to send e-mail messages to the full group of all the other participating teachers. Projects use their electronic forums in different ways. One early project used the forum to pass administrative messages about the project. However, there was enough uncertainty about who was on-line that the network manager backed up e-mail with faxes and telephone contact. Reflecting its three years of experience, Global Lab has trained some seasoned participants to function as moderators; they answer questions, share experiences, and encourage reflection about good teaching.

We raise a concern about whether the participants on projects that are limited to two or three months are a sufficient or effective community for electronic communication. Teachers need to have the time in contact to establish common purposes and develop confidence in their ability to participate in discussions. If they do establish these prerequisites, the project is ending just as they are up and running.

As an alternative, we suggest that teachers in Network Science projects be included as part of an on-going electronic community focused on Network Science. While for some purposes they will clearly want to talk only with other members of the same project, for many other purposes they will want to talk to a larger group that will have a continuing existence. An electronic forum modeled on LabNet (which focuses on supporting teacher in the practice of project-enhanced science learning) may serve teachers better.

Teacher change. Through electronic forums, we have seen examples of the impact of one excellent teacher on a group of teachers and classes. In this case, the teacher had participated in previous TERC telecommunications projects and was asked by the network manager to act informally as a "moderator" on the forum, asking and answering questions and encouraging discussion among the teachers. One example of his work in this role shows him encouraging thoughtful reflection about students' work:

> Our presentations were completed today and I would like to share the researchable questions with you. I am very much interested in the

questions your students formed and hope you will post them to the Forum.

[10 examples of student questions listed] ...

The second aspect also concerns Questions. With extra time it's possible to have students spend the effort to work a couple questions at the same time and choose the one that appears to be working a little better. It's then possible to form and reform the questions. It takes time for one teacher to work with the groups to do this. My students this year seem to want to get the question and just get it done without the thought required of more involved question forming. I think if they knew I was willing to spend the extra time, they might have been more receptive to spend more time also.

(Note from a field test teacher, 3/8/94, KN "Human Body" curriculum)

In this message, he talked about his class's experiences; in other messages, he recommended articles and books, and asked for and gave advice on how to deal with particulars situation. One measure of his effectiveness is the response of other teachers. His messages prompted many responses and succeeded in generating discussion among the participating teachers. By the end of the project, many teachers sent messages to thank him for his input and ask to continue the "electronic relationship" after the project finished (although the project network would not be available to them).

Beyond networks encouraging and assisting teachers in their professional growth, this example also demonstrates another impact of networked learning. The teacher who wrote this message had already participated in another Network Science project, and was bringing the experience and knowledge to his new group. We will continue to watch for evidence of synergy among projects, as shown in this example.

Better connections among local sites. Finally, in observing projects, we have observed that the current design of Alice makes collaboration easier among distant schools than among schools who are in the same building. In the current design, each class in a building would need its own modem and phone line–even if a local area network were available. We believe that software for collaborative inquiry needs to work as well within a school (connected on a local area network) as among schools that are in distant parts of the world (connected on a wide area network).

What Have We Learned About Scalability?

The Alice Network Software represents an important first step in reengineering telecommunications technology to fit the demanding educational market. However, in order for Network Science to become widespread, other important services will be essential.

Our testbed has been suggestive about which services must be developed. Our initial ideas were used to spark discussion among a group of publishers and educators that we brought together, and the ideas that emerged included the following:

> A project automation service would set up registration and project monitoring with minimum labor cost. A help service for a broad range of software, hardware, and curriculum products could be efficiently offered by one company using either prepaid 800- or by-the-minute 900-telephone connections. Specialized tools would assist teachers and curriculum developers to put together and distribute network curricula. As more and more curriculum units are published by teachers and school districts and distributed through servers, there will be a need for a "seal of approval" service to make recommendations about which are the best for specific purposes. Telecommunications will provide opportunities for networked courses and support services for teachers and among teachers. School districts may want to purchase technical support from a supplier rather than hire and train it own staff. (Feldman, 1994)

Another proposal that was supported by the conference participants was designed to address the problem of how teachers will find like-minded colleagues. Teachers on some networks are already reporting that they have difficulty sorting through the large numbers of messages they get from other teachers looking for collaborators. There is a need for a tool that would include a database to help teachers locate others with similar interests and needs, and ask teachers questions to assist them in describing their proposed project in standard ways.

Another aspect of scaling for Network Science is self-supporting distribution of the data analysis tools (presently part of the Alice Network Software). Distribution must accomplish two goals: provide a revenue flow sufficient to fund continuing updates, adding functions and meeting new and changing standards for telecommunications, and generate sufficient confidence so that publishers will be willing to invest in curriculum.

Our initial discussions with publishers has given us positive indications of their interest in a product like the Alice Network Software, both for school and home use. The present plan is for the software to be incorporated in an initial release of the first NGS Kids Network/Middle Grades curriculum product in September 1994.

Ironically, recent publicity about the "information superhighway" has created resistance by school administrators to any subscription charge for the use of telecommunications because they mistakenly believe that this service will be free. It is important to recognize that, despite the use of computers, there are considerable labor costs involved in supporting teachers and students in telecommunications projects. While some costs may be reduced with new software solutions, it is unlikely that support needs will be solved this way. Given our present level of experience, it is not yet possible to calculate the real costs of telecommunications, and there is certainly no consensus about who will pay for it.

Summary

The conjectures that underlie the Alice Testbed are now being tested. Network Science projects are being developed by curriculum developers and teachers, and students are collaborating in their investigations of real-world science problems. As we are learning about the issues and obstacles encountered by various testbed projects, we are creating solutions that strengthen the model. Through its work with publishers and others, we are developing an understanding of what will be needed to support widespread implementation of Network Science. In particular, we are designing services including those for project automation and for helping teachers find collaboration partners and initiate their own units; and we are working to define the commercial market for published curriculum and services.

The literature–as well as the experience of most practitioners–says over and over again: *the process of educational change is slow.* Given the experiences of large number of Alice Testbed teachers who are the pioneers in the application of network technology to science learning, we are optimistic that a new and effective paradigm for science teaching might realistically be the outcome for a large proportion of teachers who adopt Network Science.

Appendix: Description of Testbed Projects

EPA Nebraska

The Nebraska Department of Education (NDE) received a grant from the Environmental Protection Agency in the spring of 1993 to develop and implement five interdisciplinary units on the environmental sciences using telecommunications. *The Wetlands* unit was the first unit to be piloted in the fall of 1993. There were 26 participating schools, six in Nebraska, and 20 in other states with 26 teachers and approximately 700 students. The second unit, *Amphibians as BioIindicators*, is currently underway in 23 schools, with 24 teachers and approximately 600 students. The schools in both projects are "linked" through telecommunications using the Alice Network Software. In the *Wetlands* unit, live satellite broadcasts and telephone audio bridges during the satellite broadcast were used to link the schools simultaneously.

The purpose of these units is to engage students in group research projects. Using data collection tools in the field and then transferring the data to the Alice Network Software, student teams create data tables and share them with the other schools on the project through telecommunications They explain the findings at their site versus findings of the other sites, elaborate on their study, and evaluate the results.

Wetlands

Teams of students explored a wetland site their class had selected near their school. They collected data at their site, including wind speed and direction, water depth, water and air temperature, pH, relative humidity, precipitation amounts, salinity, and solar radiation. The twice-weekly satellite broadcasts and the data turnaround through the network was a crucial aspect of the curriculum. Much of the research of the student teams depended on the information that was downloaded and discussed during these sessions. An expert known as the "TV teacher" was on-line during the broadcasts to answer questions and lead a group discussion. Some schools had difficulty receiving the broadcasts due to either technical limitations or scheduling. At the end of the unit, each team presented a final oral and written research project to their class.

Amphibians As Bio-Indicators

This curriculum studies amphibian populations as indicators of ozone levels. The classes select field study sites, identify amphibians as they emerge from their eggs, and make detailed counts of amphibian populations. Because of lessons learned from the first project, the satellite broadcasts are not being used. Additionally, because of the nature of the subject matter, the classes are working in teams of two or three and share data about amphibians that emerge at different times in different parts of the country. The teams are also collecting daily weather and pH samples that are being sent through Alice Network Software and made available to all sites.

NGS Kids Network Middle Grades

The NGS Kids Network/Middle Grades is a telecommunications-based science curriculum recommended for middle school students. In the two units being field-tested, *How Does Your Body Get the Oxygen It Needs?* and *How Can You Protect the Quality of Your Water?* students assume the role of researchers as they conduct investigations. Like working scientists, they use telecommunications to exchange ideas and data with their colleagues.

Every unit is divided into four parts, each of which emphasizes a different aspect of working with data. In Part 1, they investigate qualitative data–what they can learn from making observations. In Part 2, their investigations result in quantitative data–what they can learn from taking measurements. In Part 3, they analyze the data collected from parts 1 and 2, construct a data set, exchange the data with their teammates on the computer network using the Alice Network Software, and analyze the larger data set. In Part 4, students return to questions raised in previous investigations and design their own investigations.

How Does Your Body Get The Oxygen It Needs?

Students investigated their respiratory and circulatory systems to determine how lungs, heart, and blood vessels work together to supply the body with oxygen and to remove carbon dioxide. Students studied risk factors associated with the two systems and how to reduce their potential effects. There were 31 teachers in 31 schools with approximately 800 students.

How Can You Protect The Quality Of Your Water?

In this unit students investigated a local body of surface water-river, stream, lake, reservoir, ocean, estuary, or other source-and used their findings to describe its quality and to explain how to protect it from pollution. There are 54 teachers in 52 schools with approximately 1300 students.

The Global Laboratory

Global Lab is a consortium of students, teachers, and scientists from around the world who work together to enhance secondary school science education. The project implements collaborative student research into local and global environmental issues. The project seeks to broaden students' perspectives and research opportunities by using telecommunications to link classrooms with each other and the scientific community. In September, 1993, the Global

Lab consisted of teachers and students from 120 schools, including 40 sites in Eastern Europe, Asia, and Africa, supported by a TERC staff of curriculum developers, network manager, communications director, technology developer, and researcher.

The current curriculum is based on three years of development and reflects extensive contributions from teachers in the field. It was written in a large part by a group of ten teachers who worked for three weeks last summer. The curriculum asks participating schools to select a study site nearby for students to investigate over the course of the school year. In the first semester, schools follow the first unit of the curriculum called *Building Investigative Skills (BIS)*. The activities include selecting a study site, telecommunicating with other schools, mapping the study site, collecting data at the site, analyzing data, participating in the *Global Snapshot* (synchronized, environmental measurements of data that each sites sends to all other sites), Eco research, designing experiments, and creating reports of experiments that are shared on the network. The second semester focuses on *Advanced Research*. The classes conduct advanced studies at their sites in one of four areas supported by the project: air quality, water quality, animal migrations, and stratospheric ozone. Applying the knowledge acquired during the first semester, students will design their own research projects and share their findings with the other schools.

Quincy: The Black Creek Estuary Project

A group of 21 teachers is currently exploring telecommunications and community building. They come from two schools, an elementary and middle school, in Quincy, MA, and include teachers across all subject areas, including an art teacher. They have received a small state grant to develop and implement a curriculum to study the Black Creek estuary in their town. The project was conceived by one teacher who participated in an Alice Network Software training seminar in the fall of 1993. He initiated the idea of using telecommunications between the two schools and gathered support from this group of teachers. Many of them have no experience using computers in their classrooms, much less telecommunications. They all agree that this project is worthwhile, but they are entering unfamiliar territory.

They have received content materials and training from the Massachusetts Water Resource Administration, and Alice Network Software and training from TERC. Their next step is to work in teams of two or three, set up their telecommunications accounts, and learn about water studies and telecommunications. Once they have become more familiar with the materials, they will develop a curriculum for implementation in the fall of 1994. They have asked the Alice Testbed staff to continue to assist them in their efforts.

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